Exercise interventions for older adults: A systematic review of meta-analyses

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Abstract

The evidence around which physical exercise characteristics are most effective for older adults is fragmented. We aimed to characterise the extent of this diversity and inconsistency and identify future directions in research by undertaking a systematic review of meta-analyses on exercise interventions in older adults. We searched the Cochrane Database of Systematic Reviews, PsycInfo, MEDLINE, Embase, CINAHL, AMED, SPORTDiscus and Web of Science and included: 1. Meta-analysis synthesising measures of improvement of intervention studies based on exercise on any outcome; 2. On adults aged 65+ or with a mean of 70+ years old; 3. On any type of exercise intervention, duration, frequency, intensity and mode of delivery; 4. If the intervention included multiple components, data must have been meta-analysed separately for exercise; 5. Any publication year and language. The characteristics of the reviews, of the interventions and the parameters improved through exercise were reported through narrative synthesis. Identification of the interventions linked to largest improvements was carried out by identifying the highest values for improvement recorded across the reviews. Fifty-six meta-analyses were included, which were heterogeneous in relation to population, sample size, settings, outcomes and intervention characteristics. The largest effect sizes for improvement were found for resistance training, meditative movement interventions and exercise-based active videogames. The review identified important gaps in research, including a lack of studies investigating the benefits of group interventions, the characteristics of professionals delivering the interventions associated with better outcomes, and the impact of motivational strategies and of significant others (e.g. carers) on intervention delivery and outcomes.

Keywords: old, physical exercise, intervention, systematic review, meta-analyses

INTRODUCTION

Demographics are changing, with a shift towards an ageing population. Over the last 50 years, the number of adults over 65 has tripled and by 2050, older people will represent 25% of the population worldwide [1-3].

Despite the medicine, healthcare and social advancement, longer life expectancy is not necessarily matched with increased health [4]. Engagement in exercise has multiple health benefits and can slow down some negative effects of ageing [5]. For example, exercise improves physiological outcomes in older people after long sedentary lifestyle periods [6], nonagenarians [7] and older individuals with frailty [8] or sarcopenia [9]. Exercise is defined as *'planned, structured and repetitive physical activity'* [10].

In recent years, guidelines have been set around exercise level for older adults. The World Health Organisation recommend that older adults engage in at least 150 minutes of moderate-intensity aerobic exercise or 75 or more minutes of vigorous-intensity aerobic exercise per week or an equivalent combination of the two [11]. This exercise should be performed in bouts of 10 minutes or more, to produce numerous benefits, including cardiorespiratory and muscular fitness [11-12]. Weight-bearing activities can help maintain bone and functional health [12]. Keeping physically active also reduces non-communicable disease, depression and cognitive decline. Additional health benefits can be obtained through gradually increasing the weekly time dedicated to exercise [11-12].

Older adults who have poor mobility should still engage in exercise at least three times a week to strengthen major muscle groups, maintain / improve balance and reduce the risk of falls [11-12]. Older adults who cannot exercise due to health conditions, should engage in physical activity which is commensurate to their abilities as much as possible [11]. The UK Chief Medical Officers' Physical Activity Guidelines argue that even minimal level of physical activity (e.g. standing) generates some health benefits, as opposed to being sedentary [12].

These guidelines reflect the widespread consensus that, *"If physical activity were a drug, we would refer to it as a miracle cure, due to the great many illnesses it can prevent and help treat"* [12]. Despite the overall view that exercise is beneficial, the evidence around which exercise characteristics (e.g. type of exercise, intensity, duration and frequency) are most effective for older adults is fragmented. Different types of exercise interventions have been delivered in healthy [20,21,24,26,27,30,31,34,35,37,41-45,48,49,51,53,54,72] and non-healthy older adults [22,23,25,28,32,33,36,38,39,47,50,52,55], in different types of settings (e.g. community [40,41], residential care homes [32,33], private home [42-45]), with various types of professional support (e.g. professional [26], provided by students [38]) , aiming to improve a range of outcome measurements, such as physical functioning [20,71,72], falls [21,22], and mental functioning [49,50,52]. This diversity makes comparison between different studies (and exercise configurations) highly challenging and generates inconsistent findings.

We sought to characterise the extent of this diversity and inconsistency and identify future directions in practice and research by undertaking a systematic review and synthesis of the literature on exercise in older people. The research questions were:

- How diverse are the characteristics of exercise interventions for older adults?
- How inconsistent are the findings around outcome parameters improved through exercise interventions?
- Is it possible to determine which the most effective interventions are on certain outcome parameters?

We aimed to answer these questions by:

- Objective 1. Reporting on the characteristics of exercise interventions for older adults;

- Objective 2. Investigating which outcome parameters significantly improved through which intervention characteristics (e.g. type and duration);
- Objective 3. Identifying and ranking the interventions that are linked to largest improvements on outcome parameters.

MATERIALS AND METHODS

A systematic literature review of meta-analyses was deemed appropriate to synthesise the wealth of evidence available from multiple sources into a manageable format [13]. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement [14]. Appendix A shows where in the paper each of the items in the checklist were addressed. A protocol was published in the international database of prospectively registered systematic reviews in health and social care (PROSPERO) [15].

Search

The search strategy (Appendix B) was based on the PICO (Population, Intervention, Comparison, Outcome) worksheet for conducting systematic reviews [16] and developed by an expert librarian from the University of Nottingham. Two searches were performed (one in December 2018 and one in in March 2020) in eight databases: the Cochrane Database of Systematic Reviews, PsycInfo, MEDLINE, Embase, CINAHL, AMED, SPORTDiscus and Web of Science.

Study selection and appraisal

All initial records were imported into Endnote. Duplicate records were removed. Three authors (CDL, AL, VVDW) carried out title and abstract screening and eliminated ineligible studies. Each record was independently screened by two authors to ensure accuracy in selection. The same authors then screened the full texts of the remaining records against the inclusion/exclusion criteria (below). Each record was independently screened by two authors and any disagreement was discussed to reach consensus. Numbers/reasons for exclusion were recorded. The references of the included reviews were screened to identify further eligible studies.

Inclusion criteria

The literature review is:

- A meta-analysis synthesising measures of improvement (e.g. effect sizes) of intervention studies based on exercise (operational definition in introduction) on any outcome;
- A meta-analysis on any type of exercise, duration, frequency, intensity and mode of delivery. If the intervention included multiple components (e.g. exercise and cognitive stimulation), effect sizes must have been computed separately for exercise;
- A meta-analysis on adults aged 65+ or, if the age inclusion criterion for the review was below 65 years old or was not reported, the overall sample mean was at least 70 years old;
- A meta-analysis published in any year and language.

Exclusion criteria

- Literature reviews that do not meta-analyse data, empirical studies or any other type of paper (e.g. editorials) and conference abstracts;
- Literature reviews that involved people younger than 65 years old or, if the age inclusion criterion of the review was below 65 or not reported, the overall sample mean was also below 70 years old;
- Literature reviews not including an exercise component (e.g. about functional ability or physical activity only).

Study quality appraisal

Three raters (CDL, AL and VVDW) independently assessed the quality of the included reviews through the CASP checklist for systematic reviews [(17)]. Each article was appraised by one rater only. The total possible score of the quality appraisal was ten, with higher scores showing higher quality.

Data extraction and synthesis

Data extraction was guided by the three objectives. An ad hoc form, informed by the Cochrane data extraction form [(18)], was used. The form was first piloted on a random sample of three reviews and then used to extract study characteristics (i.e. author, year, number of studies included, population, sample size, and participants' age), interventions characteristics (i.e. setting, type of intervention, duration and frequency) and findings from the meta-analyses (review outcomes and measures of improvements). The data were extracted by the main author (CDL) and checked for accuracy by two further authors (AL and VVDW).

The characteristics of the reviews and of the interventions (objective 1) were reported through narrative synthesis. In relation to the parameters improved through exercise (objective 2), one author (CDL) synthesised the data into outcomes, as they emerged from the individual reviews. The outcomes were then grouped by the same author into themes (i.e. umbrella outcomes). The process was checked for accuracy by two authors (AL and VVDW). Identification of the interventions linked to largest improvement on outcome parameters (objective 3) was carried out by identifying the highest values for improvement by outcome, recorded across the reviews.

Different studies used different measures to report on effect size (Table 1). To assist with comparing effect sizes across the different studies, absolute value test statistics (AVTS) were calculated following the procedure outlined by Altman and Bland [(19)]. Absolute value test statistics are a measure of statistical significance regarding the strength of the effect size (i.e. the larger the absolute test statistic value, the more significant the effect). Using the effect size point estimates and their corresponding 95% confidence intervals, we calculated the standard error and absolute value test statistic for each result as follows:

SE = (95% CI upper bound − 95% CI lower bound) / (2×1.96)

AVTS = |Effect size / SE|

Where the underlying measure was an Odds Ratio or a Risk Ratio, we first log-transformed the effect sizes and corresponding 95% confidence intervals before calculating their standard errors and absolute value test statistics. Once the AVTS for each study was computed, we then aggregated them by outcome/exercise/sample types using means and medians to aid our interpretation of the results. This allowed us to rank interventions, based on aggregated effect sizes.

RESULTS

Study selection

The initial search (December 2018) retrieved 1305 sources. Upon title and abstract screening, 985 were deemed ineligible. The full texts of 259 sources were screened against inclusion / exclusion criteria. One hundred and sixteen were removed as they were not meta-analyses, 85 because they had an age inclusion criterion below 65 or a mean age below 70, and 20 because they were not on exercise. Thirty-five meta-analyses were included. Upon screening of their reference lists, three more meta-analyses were added.

The second search (March 2020) retrieved 118 sources. Upon title and abstract screening, 72 were deemed ineligible. The full texts of 38 sources were screened against inclusion / exclusion criteria. Six were removed as they were not meta-analyses, 13 because they had an age inclusion criterion below 65 or a mean age below 70, and one because it was not on exercise. Eighteen meta-analyses were added in this review. The final number of meta-analyses included this review totalled 56.

Study selection is reported in Figure 1 through a PRISMA flow diagram [14].

Study quality appraisal

Results from the quality appraisal are reported in Table 2. One review (2%) scored four points [(49)], four (7%) six points [(20,36,43,50)], nine (16%) eight points [(25,34,35,37,51-55)], 19 (34%) nine points [(21-24,26,28-32,38,40,41,44,47,48,71,81,88)], and 24 (43%) 10 points [(27,33,39,45,46,72,77-80;82-87;89-94)]. The items with highest scores were clarity in the focus of the review and appropriateness of included papers (n=56, 100%). The items with lowest scores were inclusion of all relevant studies (n=40, 71%) and balance between benefits and costs (n=44, 79%).

Review characteristics

The characteristics of the included reviews are reported in Table 3. The reviews were conducted between 2000 and 2020. They were all in English, except for one in Portuguese [(22)]. The number of studies included in the meta-analyses ranged from four [(38)] to 238 [(45)] (mean = 28, SD = 38). The reviews focused on healthy older adults (n = 33; 59%) [(20,21,24,26,27,30,31,34,35,37,40-45,48,49,51,53,54,71,72,77-81,83,85,88,89,91,94)], older adults with physical health problems (including reduced physical capacity and frailty) (n = 13; 23%) [(22,23,25,32,33,47,78,81,82,84,87,90,93)] , people with cognitive impairment or dementia (n = 9; 16%) [(28,29,36,38,39,50,52,78,88)], older adults with mental health conditions (i.e. depression) (n = 2; 4%) [(55,86)] and post-menopausal women (n = 1; 2%) [(53)]. The age inclusion criteria varied: in half of the meta-analyses (n = 30; 54%) it was 65 years old [(20,21,23,24,25,26,28-31,33-35,42,44,45,50,51,53,71,80-82,86,87,89,90,92,93)] and in a third (n = 21; 37%) it was 60 years old [(22,27,36-38,40,41,43,44,46-49,55,77,78,83-85,91,94)]. Thirty-one reviews (55%) reported the mean age of participants of the included studies (range = 70-84, mean = 75, SD = 4) [(24,26-30,35,37-41,43-51,72,77-81,88-92)]. While the age inclusion criterion was not reported in three meta-analyses (5%) [(32,39,52)], and was below 60 in two (4%) [79,88], these papers were still included in the review, as the mean age of participants was above 70 (as per inclusion criteria).

The number of participants included in the meta-analyses was not reported in four cases (7%) [20,31,54,79]. In the remainders, it ranged between 291 and 159910 (mean = 6713; SD = 26415). Healthy older adults totalled 287890, older adults with cognitive impairment / dementia 63100, older adults with physical health problems 14060, older adults with mental health conditions 1659, and post-menopausal women 462.

In relation to study outcomes, 26 meta-analyses [20-34,71,72,78,79,81-84,87,89,93] (46%) focused on physical functioning (e.g. strength), physical health and physical exercise (including mobility), 19 [21,22,35-45,77,80,81,91,92] (3%) on falls-related outcomes (e.g. number of falls), injuries and mortality, 11 [22,25,32,46-48,81,82,90,93] (20%) on independence in activities of daily living (ADLs), quality of life, quality of sleep and functioning in society (participation), nine [49-52,78,81,85,87,88] (16%) on brain functioning (e.g. cognition), three [26,53,84] (5%) on musculoskeletal health and bone density, and three [54,55,86] (5%) on mood.

Objective 1: Characteristics of exercise interventions

The characteristics of exercise interventions (Table 4) were extremely diverse. In relation to delivery setting, 24 (43%) interventions [21,22,26,32,33,35,36,38,39,42-45,49,50,55,77,82,83,89,90,92-94) were delivered in the participants' homes, 14 (25%) [22,26,32,33,36,38,39,42-44,46,47,49,50] in residential retirement homes, 15 (27%) [21,25,30,35,40,41,45,47,50,55,71,86,87,90] in community settings (e.g. community centres), 11 (20%) [21,25,30,36,45,47,48,87,89,90,92] in healthcare settings (e.g. hospitals), and six (11%) [25,26,30,36,48,72] in care / nursing homes. . The interventions were delivered in multiple settings in 50% of the reviews (n = 28) [21,22,25,26,30,32,33,36,38,39,42-45,47-

[50,55,77,83,86,87,89,90,92-94]. The setting was not reported / specified in 19 reviews (34%) [20,23,24,27-29,31,51-54,78-81,84,85,88].

Intervention duration varied as well. Nine interventions (16%) lasted up to 24 weeks (6 months) [23,27,34,47,54,55,85,86,92], 27 (48%) between 25 and 52 weeks (6-12 months) [20-22,24,25,29-33,38,39,42,44,46,48,50,51,53,71,72,82,84,87,88,90,93], and 11 (20%) more than 53 weeks (more than 12 months) [26,28,45,49,52,77,78,80,81,83,91]. The information was not reported in nine reviews (16%) [35-37,40,41,43,79,89,94]. Regarding intervention frequency (i.e. number of sessions per week), seven reviews (12%) [20,21,26,30,39,85,89] included interventions requiring participants to exercise up to three times a week, 12 (21%) [23-25,31,34,38,50,51,54,72,77,88] up to five times a week and 23 (41%) [27,29,32,33,42,44,46-49,53,55,71,78,81-84,87,90-93] more than five times a week. This information was omitted in 12 (21%) reviews [35-37,40,41,43,45,52,79,80,86,94].

The interventions were either wholly based on physical exercise (n = 48; 86%) [20-28,30,31,33-36,38,39,42,44,47-55,71,72,77-81,84-94] or had several components (one of which was exercise) (n = 9; 17%) [29,32,37,40,41,43,45,46,82,83,90]. Nine reviews (16%) [29,37,39-41,43,45,52,89] did not specify the type of physical exercise. Thirty-four reviews (61%) that did provide details included strength, power and resistance training (e.g. weights, Thera-band) [21-28,32-35,38,44,46,48,50,54,55,71,72,77,78,81-88,91-93], 24 (43%) endurance (i.e. cardio fitness / aerobics / dancing / cycling) [21,22,24,28,32,33,48-51,54,55,72,77,78,81-84,86,87,91-93], 18 (32%) meditative movement (i.e. Tai-Chi / Qigong / yoga), mind-body exercises and psychomotor exercises [24,32,33,36,42,44,47,50,55,72,77,80,81,83,86,88,91], 18 (32%) balance and coordination (e.g. gait training) [21,22,24,32,33,35,38,44,48,72,79,80,82,83,91-94], 11 (20%) walking / mobility [21,25,28,38,50,80,82,83,91,92,94], 10 (18%) flexibility and stretching [21,22,24,32,33,82,83,91-93], seven (12%) ADLs plus functional exercise [28,32,33,71,80,82,91], six (11%) whole body vibration [20,26,31,33,53,83], four (7%) physiotherapy and physical rehabilitation [21,25,29,46], three (5%) occupational and recreational therapy [29,46,83], one (2%) agility training [72], and four (7%) other types of training (i.e. face training, exercise-based active videogames, aquatics, chair-based exercises, and calisthenics) [30,50,83,90]. Forty reviews (71%) focused on multiple exercise interventions [21,22,24-26,28,29,32,3335,36,38,41,43-46,48-51,54,44,71,72,77,78,80-84,86-88,91-94].

Objective 2: Outcome parameters improved through exercise

Physical functioning, physical health and physical exercise

Most reviews reported improvements in *muscle strength* [22-34]. In healthy older adults, improved strength of the lower limb was reported following progressive resistance training and multimodal exercises, the former producing larger size effects (SMD = 0.33) than the latter (SMD = 0.16) [22]. Resistance training was also found to significantly increase lower (SMD = 0.63; $p<0.05$) and upper extremity muscle strength (SMD = 1.18; $p<0.05$) [23]. Small but significant effects ($p < 0.01$) on handgrip strength were found in one review (SMD = 0.28; $p<0.05$) [83]. Supervision by clinicians during resistance training produced statistically significant effect sizes in improving overall muscle strength (SMD = 0.51; $p < 0.04$) [24]. Specifically, 10–29 additional supervised sessions produced the largest improvements (SMD = 1.12; $p<0.05$) [24].

Nutritional supplementation plus exercise, was linked to larger improvements in limb strength, compared to exercise alone (SMD = 0.33; $p<0.05$) [25]. Muscle strength of the lower limb was significantly improved when healthy older adults received Vitamin D3 alongside supervised progressive exercise, compared to exercise or Vitamin D3 separately (SMD = 0.98; $p<0.01$) [26]. Protein supplementation plus resistance training produced larger leg strength gains than physical exercise alone (SMD = 0.69; p<0.01) [27]. One review found significant effects of exercise plus protein supplementation in older adults with sarcopenia and risk of frailty on handgrip (SMD = 0.44; p<0.01) and leg strength (SMD = 0.65; p<0.01) [84]. Greater improvements in the combined exercise - protein supplementation group were found among older adults with body mass index above 30 (SMD = 0.87; p>0.05) [27]. Exercise also significantly improved muscle strength in people with cognitive impairment and dementia, following a walking and mobility training intervention (g = 0.75; p<0.01) [28]. It was found that in cardiac patients, a higher volume of exercise yielded a significant positive effect on functional recovery (MD = 27; p<0.01) and a trend towards improvement in cardiopulmonary capacity (MD = 0.72; p > 0.07) [87].

In relation to *balance*, it was found that multimodal exercise significantly improved dynamic standing balance in healthy individuals (SMD = 0.46; p<0.01) [22]. Exercise-based active video games produced larger effect sizes than conventional exercise in Berg Balance scores (MD = 4.33; p<0.05) [30]. The positive effects of exercise extended to less physically able participants. Whole Body Vibration was found to benefit dynamic balance in participants with physical limitations (SMD = -0.15; p<0.05) and in those in need of care (SMD = -0.90; p<0.05) [31]. Supervision during exercise led to larger improvements in static steady-state balance (SMD = 0.28; p<0.01), dynamic steady-state balance (SMD = 0.35; p>0.05), proactive balance (SMD = 0.24; p>0.05) and balance test batteries (SMD = 0.53; p<0.05) [24].

The reviews reported consistent improvements in *gait speed* following exercise. Multimodal exercise improved maximal (SMD = 0.31; p<0.05) and habitual gait speed (SMD = 0.50; p<0.01) [22]. Positive effects in both normal (MD = 0.06; p<0.01) and fast gait speed (MD = 0.08; p<0.01) were also reported [33]. Two reviews investigated improvements in the Short Physical Performance Battery. Improvement in the test score were reported following a combination of different exercise modalities (MD = 1.87; p<0.01) [33] and through physical exercise and Vitamin D (SMD = 1.09; $p>0.05$) [26]. Improvement in the sit-to-stand were reported in two reviews [22,30]. Chair stand was significantly improved following multimodal exercises (SMD = -0.26; $p<0.05$) and exercise-based active video games (MD = 3.99; $p<0.05$) [22, 30]. Results in the Timed-Up-and-Go (TUG) test were less consistent. While it was found that resistance exercise using elastic bands significantly increased TUG times (MD = 2.39; $p<0.01$) [34], progressive resistance training (SMD = -0.02) or multimodal exercise interventions (SMD = -0.41; $p>0.05$) had no significant effects on TUG times [22].

Two reviews investigated long-term outcomes of exercise [89,92]. One study found that the exercise interventions improved exercise time in participants immediately post intervention (SMD = 0.18; $p<0.05$) and at the six-month follow up (SMD = 0.30; $p<0.05$) [89]. However, long term effects at the one-year follow up (SMD = 0.27; $p>0.05$) and two-year follow up (SMD = 0.03; $p>0.05$) were lost [89]. Another review found that older patients recently discharged from hospital walked an average of 23 m more than controls in the three months following delivery of rehabilitation exercises ($p>0.05$) [92].

Falls-related outcomes, injuries and mortality

Several reviews investigated *number of falls* [21,22,35-45,77,80,81,91]. Participation in exercise interventions resulted in falls reduction in non-institutionalised (OR = 0.78; $p<0.01$) and institutionalised participants (OR = 0.80; $p<0.01$) [36,37]. Sherrington calculated, based on a risk of 850 falls in 1000 people followed over one year (data obtained from 59 studies included in meta-analysis), that participants to exercise intervention experienced 195 fewer falls than controls [91].

Multimodal exercise showed a particularly positive effect on reducing falls. In home-based muscle strengthening and balance retraining interventions delivered by therapists, the overall reduction of falls was 35% (IRR = 0.65; $p<0.05$) [35]. Reduced falls rate resulted from multimodal exercise interventions in older adults with reduced physical capacity (RR = 0.63; $p<0.05$) [22], and in participants with cognitive impairment (RaR = 0.68; $p<0.01$) [22] and dementia (MD = -1.06; $p<0.01$) [38, 39].

The association between delivery setting and number of falls was investigated in one review [40], reporting that home interventions did not significantly reduce falls rate (RaR = 1.27; $p>0.05$). Large effects sizes in falls reduction were instead obtained through integrating physical exercise with falls-reduction strategies, such as home visits and environment modification (OR = 0.75; $p<0.05$) [36] or risk modification (MWES = 0.06; $p<0.01$) and comprehensive risk assessment (MWES = 0.12; $p<0.01$) [37]. Interventions combining exercise and education (OR = 0.65) were more effective that those combining exercise and hazard assessment / modification (OR = 0.66) [41].

The benefits of exercise on falls rate extended beyond the active intervention period. Finnegan found significant lasting effects of exercise at 12-month follow-up (RaR = 0.79; $p<0.01$) [80]. A significant reduction in falls at 12 months was also reported in another review (MWES = 0.09; $p<0.01$) [37].

Risk of falling following exercise interventions was explored in four reviews [22,38,42,43]. Strength, mobility and balance exercises delivered in group-based interventions reduced the risk of falling by 32% (RR = 0.68; $p<0.01$) [38]. A 21% protective effect against risk of falls resulted from a multi-modal exercise intervention [21]. A review looking at the effectiveness of Tai-Chi in healthy older adults found a significant reduced pooled estimated odds ratio for falls [42]. The effect declined six months after the end of the active intervention [43].

Two reviews investigated *fear of falling.* Significantly reduced fear resulted from exercise alone (MWES = 0.02; $p<0.05$), a combination of physical exercise and education (MWES = 0.24; $p<0.05$), interventions delivered in the community (MWES = 0.22; $p<0.05$) and in participants' homes (MWES = 0.41; $p<0.05$) [43]. This review found that fear of falling decreased at four month follow up: MWES = 0.24; $p<0.05$) [43], but another [44] evidenced that the positive effects were not statistically significant at six month follow up (SMD = 0.17; $p>0.05$).. The same review [44] found no significant effect on fear of falling based on type of exercise, exercise frequency, duration of interventions, or falls risk status of participant, but a significant effect of group (SMD = 0.49; $p<0.05$) over individual delivery (SMD = 0.14; $p>0.05$).

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Eight reviews [35,39,40,45,77,81,92,94] looked at injuries resulting from falls, hospitalisation and mortality. One review found that muscle strengthening and balance exercises reduced the number of falls-related injuries by 35%, with fewer participants suffering an injury from a fall (IRR = 0.65; $p<0.05$) or being admitted to hospital (OR = 0.52; $p<0.05$)[35]. Another review confirmed that exercise significantly decreased the risk of injurious falls (RR = 0.74; $p<0.05$), and resulting fractures (RR = 0.84; $p<0.05$) [77]. Exercise was also linked to a reduction in injurious falls, when combined with vision assessment / treatment (OR = 0.17; $p<0.05$) and environmental assessment / modification (OR = 0.30; $p<0.05$) [45]. In two other reviews, however, the rate ratio for fractures related to falls did not change significantly with exercise (RaR = 1.47; $p>0.05$) [39] and exercise delivered at home did not significantly reduce falls injury rate (RaR = 1.16; $p>0.05$) [40]. Exercise was not reported having any significant effect on mortality in two reviews [(RR = 0.93; $p>0.05$) [81]; (RR = 0.96; $p>0.05$) [77]].

Independence in activities of daily living (ADLs), quality of life, quality of sleep and functioning in society

Independence in ADLs was investigated in four reviews [22,46,82,93]. Non-significant (p>0.05) effect of progressive resistance (SMD = 0.13) or multi-modal programmes (SMD = 0.37) on ADLs was reported among older adults with reduced physical capacity [22]. However, exercise improved independence in ADLs among older adults in residential care (SMD = 0.24; p<0.01) [46] and Community-dwelling frail older adults (SMD = 0.54; p < 0.01) [93].

Quality of life was the primary outcome in four reviews [20,47,81,93]. Exercise programmes did not produce significant effects on quality of life in healthy participants (RaR = 0.04; p>0.05) [81] or frail ones [(WMD = -0.18; p>0.05) [32]; MD = 0.1; p> 0.05)[93]], except for Whole Body Vibration in measures including social function (SMD = 0.73, p<0.01) and vitality (SMD = 0.78; p<0.01) [20].

Meditative movement interventions produced larger effects on *quality of sleep* than sleep therapy or usual care (SMD = -0.70; p<0.01)), regardless of type and duration of the intervention [47]. The impact of exercise on *participation in society* (i.e. individual functioning at the societal level) was investigated in one review [48]. The authors found that multicomponent interventions with an exercise component produced larger effects than exercise alone, although the difference was not statistically significant (SMD = 0.22; p>0.05) [48].

Brain functioning

Brain functioning was the primary outcome in nine reviews [49-52,78,81,85,87,88]. In healthy older adults, it was found that Tai-Chi and aerobic exercises did not reduce the risk of cognitive impairment (RR = 1.12; $p>0.05$) or decline (RR = 0.90; $p>0.05$), but reduced the risk of dementia (RR = 0.57; $p>0.05$), though non-significantly [49]. It was also found that seated exercise had a significantly positive effect on cognition (SMD = 1.20; $p<0.01$) [90]. Another review [85] found that a single aerobic/strength exercise bout was able to increase peripheral blood brain-derived neurotrophic factor concentrations (SMD = 2.21; $p<0.05$), and that an exercise programme comprising aerobic/strength training increased these concentrations significantly (SMD = 4.72; $p< 0.01$). The effectiveness of resistance and aerobic on cognition ($g = 0.24$; $p < 0.01$) was reported in another review [78]. García-Hermoso et al. [81] found improvements in healthy adults' cognition following involvement in long-term (i.e. more than 12 months) interventions (RR = 0.24; $p<0.01$).

In regards to the effects of exercise on *cognitive functioning* in people with cognitive impairment / dementia, one review found little effects on verbal fluency (MD = 1.32; $p<0.01$) and none on cognitive flexibility (MD = 6.76; $p>0.05$) and delayed memory (MD = -0.01; $p>0.05$) [50]. Another review found no effects on overall cognition (MWES = 0.21; $p>0.05$), but a significant effect on executive attention (MWES = 0.15; $p<0.05$) [51]. While higher effects were generated when exercise was delivered in group (MWES = 0.12; $p<0.01$) [52] and in sessions with a short duration and high frequency ($d = 0.43–0.50$) [88], no significant effects resulted from different intervention characteristics, such as length (MWES = 0.00; $p>0.05$) and frequency (MWES = 0.12; $p>0.05$) [52]. When comparing physical exercise intervention to computerised cognitive training, music therapy and nutrition therapy, the former produced the largest improvement on cognition (SMD = 0.35; $p<0.05$) [52].

Musculoskeletal health, bone density and muscle mass

Musculoskeletal health was explored in three reviews [26,53,84]. It was found that whole-body vibration had no significant post-intervention effects on total (MD = 0.00; p>0.05) and femoral neck (MD = 0.01; p>0,05) *Bone mineral density* (BMD) in post-menopausal women, but improvements in BMD of the lumbar spine (MD = 0.02; p<0.05) [53].

In comparison to participants who did not receive the intervention, the same review did not find significant improvements among participants in total (MD = -0.01; p>0.05), femoral neck (MD = 0.02; p>0.05) and lumbar spine BMD (MD = 0.02; p>0.05) [53]. When dividing participants by age group, the authors found no significant differences in BMD of femoral neck in women below 65 years old pre and post-intervention (MD = 0.02; p>0.05), but a significant one in BMD of the lumbar spine (MD = 0.01; p<0.05) [53].

A review comparing exercise-only versus multimodal interventions in older adults identified statistically significantly larger improvements for BMD of the femoral neck in the combined interventions (SMD = 0.02; p>0.05) [26].

A review on older adults with sarcopenia and frailty risk found that muscle strengthening exercise and protein supplementation produced significant improvements in the whole-body lean mass (SMD = 0.66; p < 0.01) and appendicular lean mass (SMD = 0.35; p < 0.01) [84].

Mood

Three reviews focused on the effect of exercise on *mood* [54,55,86]. Significant mood improvement resulted from cardiovascular and resistance training in healthy older adults (SD

= 0.38; $p<0.05$) [54]. The effect size was larger for physically active (SD = 0.27; $p<0.05$), compared to physical inactive (SD = 0.19; $p<0.05$) participants. Two reviews tested the effect of different interventions in reducing *depression* [55,86]. Heinzel et al. (2015) found that, compared to control conditions at post-treatment, there was a significant reduction in depression following aerobic exercise (SMD = -0.64; $p<0.05$), resistance training (SMD = -0.76; $p<0.05$) and alternative exercise (i.e. Tai Chi, Qi Gong, dancing) (SMD = -0.97; $p<0.05$) [55]. When differentiating by intervention characteristics, the authors identified a significant effect size for supervised training (SMD = -0.77; $p<0.05$) [55]. Miller et al. (2020) found that, compared with controls, mind-body exercise showed the largest improvement on depressive symptoms (g = −0.87 to −1.38), followed by aerobic exercise (g = −0.51 to −1.02), and resistance exercise (g = −0.41 to −0.92) [86].

Objective 3: Ranking of interventions, based on aggregated effect sizes

Table 5 ranks interventions based on their aggregated effect sizes, from largest to smallest improvements. In brief, the largest effect sizes were found for interventions based on resistance training. The smallest effect sizes were found for whole body vibration interventions.

DISCUSSION

This systematic review of meta-analyses synthesised the evidence on exercise interventions in older adults to characterise the extent of the diversity and inconsistency of the literature in this area. We also aimed to identify gaps in the literature, to suggest future directions in research.

Overall, the meta-analyses found that resistance training supported by nutritional supplementation significantly improved muscle strength, while multi-modal exercises and body vibration, in particular if supervised, produced significant balance improvements. Resistance training and multi-modal exercises might improve general physical performance measures. The evidence for exercise interventions to reduce falls and fear of falling was inconsistent. The effect might depend on place of living, clinical group, setting and the integration of additional strategies, such as home modifications and nutritional supplementation. It was found, however, that multi-modal exercise interventions reduced the risk of falling. The evidence regarding exercise to reduce falls-related injuries was inconsistent and its effectiveness might depend on additional intervention components, such as environmental or visual assessments. Overall, the meta-analyses showed that quality of life might be improved through some forms of exercise (Whole Body Vibration) and in some groups (healthy older adults), but not in others (people with frailty). Regular meditative movement exercise might be beneficial for quality of sleep. The evidence regarding exercise for improving cognitive function and preventing cognitive impairment was inconsistent, but physical exercises might be more effective than music or nutritional therapies or cognitive training.

This work is characterised by certain strengths and limitations. In relation to limitations at the level of the individual meta-analyses, there was great diversity in the studies included in these, and thus synthesised data on length, frequency and intensity of exercises, was poorly reported. Most meta-analyses included multi-component (e.g. resistance and endurance training) interventions and did not report results separately for individual components, making it difficult to associate exercise type with effect sizes. In some instances, there was no description of the type of exercise investigated in the meta-analysis, which were only referred to as “exercise”. The meta-analyses were also extremely heterogeneous in target population, numbers of studies / participants included and primary outcome.

There were also limitations at the review level. Each meta-analysis was appraised in its quality by one rater only, which might have caused single-rater bias. There are also limitations inherent to the use of the CASP. For example, the CASP does not attribute a score to reporting of sample size, which is key information required for power calculation of intervention effectiveness. Despite the lack of this information, two meta-analyses still scored 8 and 9 on the CASP. We therefore urge caution in interpreting results of our quality appraisal, as they reflect the quality of the meta-analyses only in relation to the specific aspects included in the CASP. Also, given the diversity of the studies included in this review, it was impossible to meta-analyse data. Although we were not able to synthesise a pooled estimate from all the studies, we generated a comparison metric (AVTS) for each study and then grouped the studies based on type using means and medians, to give us an indication of which study types appear to generate the strongest/weakest effect sizes. However, caution is needed when drawing conclusions from our findings, given that we combined very different interventions and that the AVTS metric is based, in many instances, on data aggregated from few reviews.

Nonetheless, the aggregated metrics can represent essential groundwork, which can inform future literature reviews with a narrower scope. For example, given the potential largest effect of resistance training, future research could explore whether the effects of this type of exercise also extend to “non-clinical” outcomes, such as changes in physical activity behaviour (i.e. increased engagement of participants in exercise, following delivery of resistance training interventions). This is particularly relevant, considering that, in order to achieve maximum benefits, adherence to exercise is crucial [73] and that research has evidenced poor adherence to exercise among older adults [74-76].

The AVTS suggests that studies delivering resistance training have the largest improvements. This is in line with previous research, adding to the evidence that resistance training is beneficial for musculoskeletal health, promotes the maintenance of functional abilities, and protects from osteoporosis, sarcopenia and lower-back pain [56]. There is also mounting evidence around the protective effect of resistance training against health conditions typically associated with ageing, including diabetes, heart disease, and cancer [56]. Research has found that a positive impact on insulin resistance, resting metabolic rate, glucose metabolism, blood pressure, body fat, and gastrointestinal transit time can be obtained even through two 20-minute resistance training sessions a week [56].

In relation to the other types of interventions, Tai-Chi and meditative movements exercise studies reported larger effect sizes that those delivering purely physical types of exercise, such as aerobics, though it must be recognised that the AVTS for these was based on fewer reviews. It might be that less physically-intensive types of exercises are more suitable to an ageing population, thus generating more improvements.

The promising results of exercise-based videogames emerging from the AVTS reflect the growing evidence around the benefits of Assisting Technology (AT) in improving the lives of older adults. AT is defined as *'Any device or system that allows an individual to perform a task that they would otherwise be unable to do, or increases the ease and safety with which the task can be performed'* [57] and its contribution to older people's independence and autonomy has been evidenced in a number of studies. Despite the promising results, however, there is contradictory evidence around the acceptability of AT from older people [58, 59]. Acceptability, in the context of physical exercise for older people, where low levels of engagement in the prescribed programmes are common [60], is a crucial aspect to ensure adherence to the exercise regime, and intervention effectiveness.

The AVTS revealed that larger effect sizes were obtained through multimodal interventions (e.g. resistance and cognitive training) as opposed to non-multi-modal formats. This is in line with previous evidence around the benefits of multimodal exercises, such as dual-tasking (i.e. undertaking a physical and cognitive task simultaneously) [61], resulting in a growing popularity of exercise programmes for people with dementia and cognitive impairment which feature multimodal interventions [62]. It was also found that integration of physical exercise with preventative / educational initiatives (e.g. falls education) was associated with larger effect sizes than without. This finding echoes recent theoretical developments in behaviour change theories, pointing at the crucial role of information / education about physical exercise (and its benefits) in boosting motivation to exercise initiation and adherence [63].

This review also evidenced important gaps in research that need addressing. The reviews on group exercises suggest that this delivery format yields similar effect sizes as individual exercises on several outcomes. There might be added values to group delivery which go beyond the physical benefits. For example, group activities may promote social integration and maintenance of a social identity role, particularly in individuals who are at risk of social exclusion, such as older people living in rural areas [64] or with dementia [65]. The motivational argument also seems to validate group delivery. Participants to group interventions can encourage each other and boost intrinsic motivation to engage in physical exercise [66]. In the context of a group programme, there is also the potential for information sharing between participants. Given the inconsistency of the evidence around group exercises, however, it is crucial, to generate further evidence to examine their potential.

Few reviews reported long-term adherence to exercise and its impact, once the intervention period is finished. In the few instances where adherence and benefits were investigated longitudinally, the results were inconsistent. It would be relevant, therefore, to explore long-term effects of interventions, which can go beyond the mere physical benefits and strategies on how to best obtain them. Research has found, for example, that the input of professionals delivering exercise interventions might represent a resource for long-term engagement in PA, as they might provide information on services and support networks available in the community, which might help older people to maintain PA levels [67] and gain long-term benefits.

Physical functioning outcomes, including functioning, falls and musculoskeletal health, were the primary focus of 80% of the reviews, while psycho-socio-emotional variables (e.g. mood and affect, quality of life, independence) only amounted to roughly 20%. It was also surprising to note that only one multimodal intervention [82] featured motivational strategies . Given the relevance of motivation in mediating adherence to exercise interventions (and in turn their effect on physical outcomes) [60, 68], further research in this area is needed.

Interestingly, none of the interventions focused on the role of significant others (e.g. family, friends and caregivers) as contributing to improved outcomes. In the context of physically /cognitively impaired individuals in particular, carers might become key agents in intervention success [69]. It is therefore pivotal to conduct research in this area. None of the reviews investigated or described which characteristics of professionals or which dynamics in the professional-client rapport were associated with greatest effect sizes. Previous literature indicates that the technical knowledge and skills of trained professionals ensure optimal adherence exercise [70]. The motivational support provided by professionals can also be instrumental for higher uptake and in turn larger improvements in intervention outcomes. Further research, therefore, is also needed in this respect.

In conclusion, this review found that exercise interventions for older adults are extremely diverse, presenting findings that are mostly inconsistent. We were able to aggregate some of the effect sizes reported in the reviews, which seem to suggest the effectiveness of resistance training, meditative movement interventions and exercise-based active videogames. We advocate for further, more focused review work, to confirm the trends we have identified in this work. The review also identified important gaps in research, including a lack of studies investigating the benefits of group interventions, the characteristics of professionals delivering the interventions associated with better outcomes, the impact of motivational strategies on intervention outcomes and the impact of significant others (e.g. carers) in intervention delivery.

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Figure 1. Selection of papers

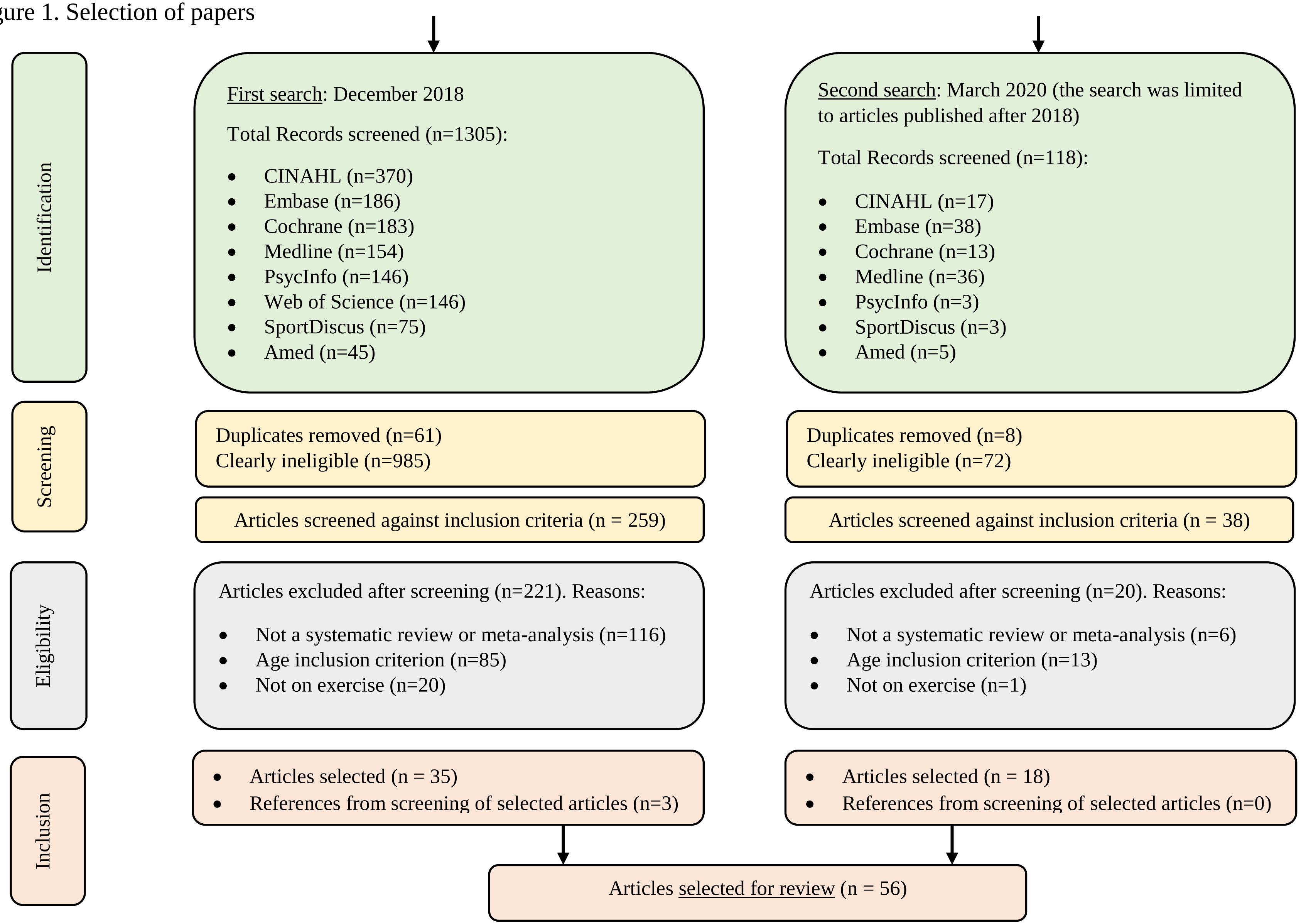

Table 1. Measures for effect sizes used in the studies

Effect size measure	**Abbreviation**
Standard Mean Deviation	SMD
Hedge's g	g
Mean Deviation	MD
Odds Ratio	OR
Incidence Rate Ratio	IRR
Rate Ratio	RaR
Mean Weighted Effect Size	MWES
Relative Risk	RR
Weighted Mean Difference	WMD

Table 2. Quality appraisal

Main author, year	**Item 1**	**Item 2**	**Item 3**	**Item 4**	**Item 5**	**Item 6**	**Item 7**	**Item 8**	**Item 9**	**Item 10**	**Yes (n)**
Antoniak 2017	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	9
Arent 2000	Y	Y	Y	U	Y	Y	U	Y	Y	Y	8
Burton 2015	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	9
Chan 2015	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Cheng 2018	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	9
Chou 2012	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	9
Crocker 2013	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
de Souto Barreto 2018	Y	Y	U	Y	U	Y	N	N	U	N	4
de Souto Barreto 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Fairhall 2011	Y	Y	Y	Y	Y	Y	Y	U	Y	Y	9
Falck 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Farlie 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Finnegan 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
García-Hermoso 2020	Y	Y	Y	U	Y	Y	Y	Y	Y	Y	9
Gates 2013	Y	Y	U	Y	Y	N	N	U	Y	Y	6
Giné-Garriga 2014	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Guo 2014	Y	Y	U	N	U	Y	Y	U	Y	Y	6
Heinzel 2005	Y	Y	Y	Y	U	Y	Y	Y	U	Y	8
Heyn 2004	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	9
Heyn 2008	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	9
Hill-Westmoreland, 2002	Y	Y	N	Y	Y	Y	Y	Y	Y	U	8
Hu 2016	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Jung 2009	Y	Y	N	U	Y	Y	Y	Y	N	U	6
Karr 2014	Y	Y	U	Y	Y	Y	Y	Y	Y	U	8
Kuijlaars 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10

Kumar 2016	Y	Y	Y	Y	Y	Y	Y	Y	Y	U	9
Labott 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Lacroix 2017	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	9
Liang 2018	Y	Y	U	Y	Y	Y	Y	Y	Y	U	8
Liao 2017	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Liao 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Liu 2017	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	9
Marín-Cascales 2018	Y	Y	U	Y	Y	Y	Y	Y	Y	N	8
Marinus 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Miller 2020	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Naseri 2018	Y	Y	Y	Y	Y	Y	Y	Y	Y	U	9
Pengelly 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Pessoa 2017	Y	Y	U	Y	Y	U	U	Y	Y	N	6
Robertson 2002	Y	Y	Y	N	Y	Y	Y	N	Y	Y	8
Rogan 2017	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	9
Sanders 2019	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	9
Sansano-Nadal 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Sexton 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Sherrington 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Sohng 2005	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	9
Steib 2010	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	9
Taylor 2018	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	9
Tricco 2017	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Van Abbema 2015	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Verweij 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Wright 2018	Y	Y	Y	Y	Y	Y	Y	Y	N	N	8
Wu 2015	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	9
Yamamoto 2016	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	9
Yeun 2017	Y	Y	Y	N	Y	Y	Y	Y	N	Y	8
Zhang 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Zhao 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
Yes (n)	56	56	40	49	54	55	53	51	52	44	

1. Did the review address a clearly focused question?
2. Did the authors look for the right type of papers?
3. Do you think all the important, relevant studies were included?
4. Did the review's authors do enough to assess quality of the included studies?
5. If the results of the review have been combined, was it reasonable to do so?
6. What are the overall results of the review? (i.e. Are the review's "bottom line" results clear?)
7. How precise are the results?
8. Can the results be applied to the local population?
9. Were all important outcomes considered?
10. Are the benefits worth the harms and costs?

Y = yes; N = No; U = Uncertain

Table 3. Review characteristics, as reported in the individual studies

Main author, year	Studies included (n)	Target population	Sample size (n)	Age	Review outcome
Antoniak 2017	7	Older adults	792	Inclusion: 65+ or mean ≥65; mean age: 72.8	Musculoskeletal health (i.e. muscle strength, bone mineral density, timed-up and go, lean mass, balance, endurance, sit-to-stand test, normal walking speed and chair stand)
Arent 2000	32	Older adults	Not reported	Inclusion: 60+ or mean age 65+	Mood (i.e. negative and positive affect)
Burton 2015	4	Older adults with dementia or cognitive impairment	336	Inclusion; 60+ (at least 50% of the sample); mean age: 80	Mean falls and faller status (i.e., faller versus non-faller)
Chan 2015	7	Older adults with dementia or cognitive impairment	781	Mean age: 80	Number of falls
Cheng 2018	49	Older community dwellers	27740	Inclusion: 60+; age range: 67.5 to 88.0; mean age: 73.0	Falls-related outcomes (number of fallers, length of follow-up, effect of the intervention)
Chou 2012	8	Frail older adults	1068	Age range 75.3 - 86.8	Physical function assessed by the Timed Up & Go (TUG) test, gait speed, or Berg Balance Scale (BBS), performance in ADLs evaluated by the validated questionnaire or reliability inventory, and QOL evaluated by the Medical Outcomes Study 36-Item Short-Form Health Survey
Crocker 2013	13	Older residents in long-term facilities	2379	Inclusion: 60+; mean age: 84	Independence in ADLs measured through Barthel Index, FIM, Katz Index of Independence in ADL, Physical Self-Maintenance Scale and the Minimum Data Set
de Souto Barreto 2018	5	Older adults	2878	Inclusion: 60+; mean age: 75.2	Onset of dementia and cognitive impairment

de Souto Barreto 2019	40	Older adults	21868	Inclusion: 60+; mean age: 73.1	Risk of falls, fractures, hospitalizations, and mortality
Fairhall 2011	15	Older adults	3616	Inclusion: 60+; mean age: 74.6	Participation in life roles
Falck 2019	48	Healthy older adults, or frail, or with cognitive impairment	6281	Inclusion: 60+; mean age: 73	Physical and cognitive function
Farlie 2019	95	Older adults	Not reported	Inclusion: 55+; mean age: 74.5	Balance
Finnegan 2019	24	Older community dwellers	7818	Inclusion: 65+; mean age: 70	Rate of falls
García-Hermoso 2020	99	Healthy older adults and clinical older adults	28523	Inclusion: 65+; mean age: 74	Mortality, falls and fall-associated injuries, fractures, physical function, quality of life, and cognition
Gates 2013	14	Older adults with cognitive impairment	1695	Inclusion: 65+; age range: 65-95; mean age: 76	Validated neuro-psychological test of cognition reported at baseline and follow-up
Giné-Garriga 2014	19	Frail older adults	2063	Inclusion: 65+	Performance-based measures of physical function such as mobility, gait, muscular strength, balance, endurance, and disability in ADL
Guo 2014	111	Older adults with/without cognitive impairment	51551	Inclusion: mean age ≥60; age range: 64.5 - 89.0	Number of falls
Heinzel 2005	18	Older adults with depression	1063	Inclusion: mean age>60	Depression
Heyn 2004	30	Older adults with cognitive impairment and dementia	2020	Inclusion: mean age >65; age range: 66–91; mean age: 80	Physical fitness
Heyn 2008	41	Older adults with / without cognitive impairment	2921	Inclusion: mean age>65; age range: 68–91; mean age: 81	Endurance and strength outcomes
Hill-Westmoreland, 2002	12	Older adults	4074	Inclusion: mean age >60; mean age: 76.5	Number of falls
Hu 2016	10	Older adults	2850	Inclusion: 65+; age range: 64-84	Number of falls
Kuijlaars 2019	9	Older patients with hip fractures	602	Inclusion: 65+	Mobility, Activities of daily living, endurance, gait , balance, strength

Labott 2019	24	Healthy community dwellers	3018	Inclusion: 60+	Handgrip strength
Lacroix 2017	11	Older adults	621	Inclusion: 65 or +; age range: 65.3-81.1; mean age: 73.6	Balance and muscle strength
Liang 2018	17	Older adults with cognitive impairment or Alzheimer's	1747	Age range: 70-83	Cognition
Liao 2017	17	Older adults	892	Inclusion: mean age ≥60; mean age: 73.4	Body composition and physical function
Liao 2019	19	Hospitalized, institutionalized, or community-dwelling elderly individuals with a high risk of sarcopenia or frailty and physical limitations	1888	Inclusion: 60+	Muscle mass, sarcopenia, leg strength or physical function
Liu 2017	23	Older adults with reduced physical capacity	2019	Inclusion: Mean age 60+	Muscle strength of the lower extremity, physical functioning, activities of daily living, and falls
Jung 2009	6	Older adults	957	Inclusion: 60+; mean age: 76.5	Fear of falling, as measured by Falls Efficacy Scale (FES), the Activities-Specific Balance Confidence Scale (ABC) and the Survey of Activities and Fear of Falling in the Elderly (SAFE)
Karr 2014	25	Older adults	1878	Inclusion: 65+; mean age: 74	Executive function (working memory, inhibition, executive attention, problem solving, and fluency
Kumar 2016	30	Older adults	2878	Inclusion: 65 or +	Fear of falling measured through scales measuring falls efficacy, balance confidence and concern or worry about falling
Marín-Cascales 2018	10	Post-menopausal older women	462	Inclusion: mean age >65	Bone health (total, femoral neck, and lumbar spine bone mineral density)
Marinus 2019	17	Older adults	982	Inclusion: 60+	Peripheral Blood Brain-Derived Neurotrophic Factor Concentrations
Miller 2020	15	Older adults with depression	596	Inclusion: 65+	Depression
Naseri 2018	16	Older adults recently discharged from hospital to the community	3290	Inclusion: mean age ≥60; age range: 70-84; mean age: 70	Falls
Pengelly 2019	11	Older cardiac adults	1797	Inclusion: 65+	Physical and cognitive function

Pessoa 2017	9	Older adults	Not reported	Inclusion: 65 or +	Muscle strength and quality of life
Robertson 2002	4	Older adults	1016	Inclusion: mean age ≥65; mean age: 82.3; age range: 65-97	Number of falls and number of injuries resulting from falls
Rogan 2017	33	Older adults	Not reported	Inclusion: 65+	Postural control (static, dynamic and functional balance)
Sanders 2019	36	Adults with and without cognitive impairments	2007	Inclusion: 18+; mean age: 73	Cognition
Sansano-Nadal 2019	12	Older community dwellers	1991	Inclusion: 65+; mean age: 76	Time spent doing exercise at six months follow-up
Sexton 2019	14	Older adults living with a health condition or impairment	921	Inclusion: Mean age 65+; mean age: 81	Impairment, activity and participation levels
Sherrington 2019	108	Older community dwellers	23407	Inclusion: 60+; mean: 76	Falls
Sohng 2005	8	Older adults	843	Inclusion: 65+; age range: 71-84	Falls, balance and muscle strength
Steib 2010	29	Older adults	1313	Inclusion: mean age ≥65	Strength and function
Taylor 2018	18	Older adults	765	Inclusion: > 50% of participants > 65 years; mean age community-dwelling participants: 75.6; mean age hospitalized or nursing home older participants: 85.3	Physical performance
Tricco 2017	238	Older adults	159910	Inclusion: 65 or +; age mean: 78.1	Injurious falls and fall-related hospitalizations
Van Abbema 2015	25	Older adults	2389	Inclusion: mean age ≥65; age mean: 75.8	Gait speed
Verweij 2019	15	older adults discharged from hospital	1255	Inclusion: 65+; mean: 74	Mobility and hospital re-admission
Wright 2018	11	Nutritionally vulnerable older adults	1459	Inclusion: mean age ≥65	Physical functioning, quality of life and nutritional status

Wu 2015	14	Older adults, older patients after stroke and older adults with diabetes	1225	Inclusion: mean age >60; age mean: 70.3	Quality of sleep
Yamamoto 2016	5	Older adults with coronary heart disease	291	Inclusion: mean age ≥65	Muscle strength, exercise capacity and mobility
Yeun 2017	19	Older adults	649	Inclusion: mean age ≥65	Flexibility and balance
Zhang 2019	22	Community-dwelling frail older adults	2456	Inclusion: 65+	Physical functioning, activities of daily living, quality of life
Zhao 2019	25	Older adults	7076	Inclusion: 60+	Falls-related injuries and hospitalisation

Table 4. Characteristics of exercise interventions

Main author, year	Type of exercise	Setting	Intervention duration	Intervention frequency
Antoniak 2017	Supervised, progressive exercise sessions including a warm-up and strengthening exercises using commercial weight and pulley machines, Thera-bands, weighted vests, whole body vibration machines for resistance balance	Home, retirement community, nursing homes, service flats or cloistered communities	3-24 months	24-156 sessions
Arent 2000	Exercise such as cardiovascular, resistance training, or combination	Not reported	1-12+ weeks	any
Burton 2015	Strength, balance, and mobility exercises supervised by physiotherapists, occupational therapists, or physiotherapy students who were trained and supervised by physiotherapists	Residential care or home	3-12 months	1-5 p/wk
Chan 2015	Home-based individual and group physical exercise	Residential care or home	3-12 months	1-5 times every two weeks
Cheng 2018	(1) Usual care (no specific fall intervention), (2) education, (3) risk assessment and suggestion, (4) exercise, (5) medical care, (6) hazard assessment and modification, (7) combination of education and risk assessment, (8) combination of education and exercise, (9) combination of risk assessment and exercise, (10) combination of exercise and Hazard assessment, and (11) multifactorial intervention (MFI), including three or more interventions	Community (Excluding hospital, nursing home, or other long-term care facilities)	Not reported	Not reported
Chou 2012	Flexibility, low- or intensive-resistance, aerobic, coordination, balance, and Tai-Chi exercises; repetitive performance of ADLs; and task-oriented or gait training	Residential care or home	3-12 months	1-7 p/wk
Crocker 2013	Group exercise classes including resistance Training or individual sessions of physiotherapy and / or occupational therapy	Long-term care facilities	10 weeks – 12 months	2-6 p/wk

de Souto Barreto 2018	Tai-chi or multicomponent exercises or aerobic exercises	Residential care or home	12-24 months	2-6 p/wk
de Souto Barreto 2019	Aerobics, resistance training, Tai-Chi, dance or multicomponent	Home or community	12 months +	1.5-5 p/wk
Fairhall 2011	Single interventions (e.g. endurance, strength, balance) or a component of multiple Interventions, one of which is physical exercise	Aged care facilities or hospital settings	1.5-12 months	1-7 p/wk
Falck 2019	Aerobic, resistance and multicomponent	Not reported	2 months +	+ 1 p/wk
Farlie 2019	Balance exercises	Not reported	Not reported	Not reported
Finnegan 2019	Gait, balance and functional training, Tai Chi, walking	Not reported	6-24 months	Not reported
García-Hermoso 2020	Multicomponent exercise, muscle strength, aerobic training and Tai Chi	Home or community setting	52-208 weeks	1 – 7 p/wk
Gates 2013	Various types, including aerobic exercise, walking, resistance training, balance and aerobic training, balance and coordination training, Tai Chi, and face exercises	Gymnasiums, YMCA, local community, care centre, residential site or private home	6-52 weeks	2-4 p/wk
Giné-Garriga 2014	Combinations of aerobic, balance, flexibility, endurance, and strength exercises; combinations of balance and strength exercises; strength exercise programs; a stretching intervention; activities related to maintain and improve performance in ADL; progressive resistance-training program using weighted vests; the addition of visual computer feedback to balance training, whole-body vibration with exercise, or Tai Chi	Residential care or home	10 weeks – 12 months	1-7 p/wk
Guo 2014	Various single or multicomponent physical exercise interventions and tai-chi	Medical centres, hospitals, nursing homes, care homes, and private homes	Not reported	Not reported
Heinzel 2005	Aerobic exercise, resistance training, alternative exercise (Tai Chi, Qi Gong, dancing) and combined aerobic and resistance exercise	Community, including individual homes	6-24 weeks	1-6 p/wk
Heyn 2004	Walking (mobility training), combined walking with different types of isotonic exercises, chair exercises, aerobic dance, strength training with weights, stationary cycling combined with exercises, and skill-based functional exercise	Not reported	2-112 weeks	1-6 p/wk

Heyn 2008	Exercise programmes, rehabilitative exercises, fitness, or recreational therapy	Not reported	2-40 weeks	2-6 p/wk
Hill-Westmoreland, 2002	Exercise-focused interventions only and exercise interventions with risk modification	Not reported	Not reported	Not reported
Hu 2016	Tai-Chi	Residential care or home	6-12 months	16-120 hours a week
Kuijlaars 2019	Aerobics, walking, strength exercises, resistance, weights, functional exercises, balance training, stretching, cognitive and behavioural strategies, environment modification, counselling, self-efficacy motivational strategy	Home	1 – 12 months	2-7 p/wk
Labott 2019	Aquatics, walking, flexibility exercises, aerobics, strength, balance, cognitive tasks, cycling, Thera band, TRX training, chair exercises, endurance, recreational training, resistance training, whole body vibration, dancing, Tai chi, calisthenics	Home and community	1 month – 36 months	1-10 p/wk
Lacroix 2017	Resistance, static/dynamic balance, strength, flexibility, endurance and stretching exercises, and Tai-Chi	Not reported	4-44 weeks	2-5 p/wk
Liang 2018	Physical exercise (unspecified)	Not reported	12-54 weeks	Not reported
Liao 2017	Resistance exercises	Not reported	8-24 weeks	2-7 p/wk
Liao 2019	Resistance, aerobic training, multicomponent exercise	Not reported	<3months – 9 months	2-7 p/wk
Liu 2017	Progressive resistance strength exercise and multimodal exercise including strengthening, balance, stretching, endurance or aerobic exercise	Residential care or home	5 weeks – one year	2-3 p/wk
Jung 2009	Interventions for preventing falls or the fear of falling, including combined exercise and education intervention, an exercise intervention only, or a hip protector	Residential care or home	Not reported	Not reported
Karr 2014	Aerobic and non-aerobic exercise	Not reported	4-52 weeks	1-5 p/wk
Kumar 2016	Tai Chi and yoga, balance training, and strength and resistance training	Home or places of residence without nursing care or rehabilitation)	<12 - >26 weeks	1-4+ p/wk
Marín-Cascales 2018	Whole body vibration	Not reported	12-52 weeks	2-7 p/wk
Marinus 2019	Strength, resistance or multicomponent exercise	Not reported	6-24 weeks	2-3 p/wk
Miller 2020	Aerobic, resistance or mind-body exercise	Community or residential care	4-16 weeks	Not reported

Naseri 2018	Falls prevention interventions, including home hazard modification, home exercise programme, and cholecalciferol therapy	Community	Not reported	Not reported
Pengelly 2019	Aerobic and resistance training	Inpatient, outpatient, home-based or community	1 week – 6 months	1-7 p/wk
Pessoa 2017	Whole body vibration	Not reported	6-52 weeks	2-3 p/wk
Robertson 2002	A program of muscle strengthening, and balance retraining exercises designed specifically to prevent falls and individually prescribed and delivered at home by trained health professionals	Private home	Not reported	Not reported
Rogan 2017	Whole body vibration	Not reported	<10 – 52 weeks	3-5 p/wk
Sanders 2019	Aerobic, anaerobic, multicomponent or psychomotor exercise	Not reported	4-52 weeks	1-5 p/wk
Sansano-Nadal 2019	Unspecified exercise	Community, hospital, home	8 weeks – 24 months	2-3 p/wk
Sexton 2019	Seated exercise	Residential care facilities, day care centres, home, hospital	6 weeks – 7 months	1-7 p/wk
Sherrington 2019	Balance and functional exercises, resistance exercises, flexibility training, Tai Chi, dance and walking	Community	5 -130 weeks	1-3+ p/wk
Sohng 2005	Strength, balance, stretching, endurance, mobility, physiotherapy and walking	Community, including private home, geriatric hospital inpatients and outpatients	1-12 months	1-3 p/wk
Steib 2010	Resistance training, including progressive resistance training, power training, eccentric resistance training, isometric resistance training and functional task training	Community	8-52 weeks	2-7 p/wk
Taylor 2018	Exercise-based active video games (AVGs)	Community, care homes and acute hospital	3-30 weeks	2-3 p/wk
Tricco 2017	Exercise; combined exercise and vision assessment and treatment; combined exercise, vision assessment and treatment, and environmental assessment and modification; combined clinic-level quality improvement strategies (e.g., case management), multifactorial assessment and treatment (e.g., comprehensive geriatric assessment), calcium supplementation, and vitamin D supplementation	Private home, clinics and the community	1- 260 weeks	Not reported

Van Abbema 2015	Progressive resistance training, endurance and strength training, Tai Chi, balance training, salsa-dancing training, or agility training	Community and long-term care institutions	9-48 weeks	1-5 p/wk
Verweij 2019	Walking, endurance exercises, strengthening exercises, and balance and stretching exercises	Nursing facilities, outpatient clinics, or home	2 weeks – 12 months	1-6 p/wk
Wright 2018	High intensity and/or progressive resistance training, Nordic walking and intensive physiotherapy rehabilitation	Community, acute settings and care centres	12 days – 9 months	1-5 p/wk
Wu 2015	Meditative Movement Interventions including Tai chi, yoga, and qigong	Community, long-term residential homes for the elderly, outpatient departments of rehabilitation facilities/hospitals, community seniors’ centres and physicians’ offices	12-24 weeks	1-7 p/wk
Yamamoto 2016	Resistance training	Not reported	6-24 weeks	3-5 p/wk
Yeun 2017	Resistance exercise using elastic bands	Community	5-20 weeks	1-4 p/wk
Zhang 2019	Aerobic, endurance, resistance or strength exercise, flexibility training and balance training, multi-component exercise	Community, home	8-48 weeks	1-7 p/wk
Zhao 2019	Balance exercises, walking, multi-component exercise	Community, home	Not reported	Not reported

Table 5. Ranking of interventions, based on aggregated effect sizes

Intervention type	Mean AVTS	Median AVTS	Number of studies
Resistance training	5.00	3.75	9
Meditative movement interventions	4.92	4.92	2
Exercise-based active videogames	3.60	3.60	2
Tai-Chi	3.46	3.96	3
Alternative exercise	3.12	3.12	1
Aerobic exercise	2.63	2.45	7
Multi-modal exercise	2.60	2.44	3
Physical exercise (unspecified)	2.45	2.41	87
Non-multi-modal exercise	1.76	1.76	1
Whole Body Vibration	1.63	1.22	18
Overall	**2.58**	**2.45**	**133**

Appendix A. PRISMA Checklist and where in the paper each item was addressed

Section/topic	#	Checklist item	On page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	3, 4
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	4, 5
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	5
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	6, 7
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	5
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	Appendix B
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	6
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	7, 8, 9

Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	7, 8, 9
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	7
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	8, Table 1
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	8, 9
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	22, 23
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	9
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	9 and Figure 1
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	10, 11, 12, 13, Tables 3 and 4
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	10 and Table 2
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	13-21 and Table 4
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	13-21
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	22, 23
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	21 and table 5

DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	21-25
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	22, 23
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	25-27
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	1

Appendix B

Search Strategy for PsycInfo, Medline, Embase

1. (old* OR geriatr* OR aged OR ageing OR aging OR elder*).m_titl
2. Exercise.m_titl
3. meta-analysis.mp. or exp Meta Analysis/
4. 1 AND 2 AND 3

31 PsychInfo 3 from 2019, 3 selected
162 Medline 36 from 2019, 31 selected
206 Embase 38 from 2019, 32 selected
19 AMED, 5 from 2018, 5 selected

Search strategy for CINHAL and Sportdiscus

1. (old* OR geriatr* OR aged OR ageing OR aging OR elder*).m_titl
2. Exercise.m_titl
3. meta-analysis.m_titl
4. 1 AND 2 AND 3

71 Cinhal / 17 from 2019, 10 selected
23 Sportdiscus / 3 from 2019, 3 selected

Search Strategy for Web of Science

1. TI=(old* OR geriatr* OR aged OR ageing OR aging OR elder* OR “later life”)
2. TI=(exercise)
3. TI=(meta-analysis)
4. 1 AND 2 AND 3

146 results / 3 results from 2019, 3 selected

Cochrane Database of Systematic Reviews

1. (old* OR geriatr* OR aged OR ageing OR aging OR elder* OR “later life”).ti,ab
2. Exercise.ti,ab
3. Meta-analysis.ti,ab

127 results, 13 results from 2019, none selected

38 after duplicates’ removal

19 selected for review. Reasons for exclusion: age (n=13), not meta-analysis (n=5), not on exercise (n=1)